NORWICH
CLIMATE
COMMISSION

Norfolk and Norwich climate projections and potential adaptation to the impacts

2022 Working Paper 1

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The Norwich Climate Commission is an independent advisory body set up to bring actors from the public, private and third sectors together to support, guide and track the impact of ambitious climate change and sustainability actions across Norwich. We are a partnership of Norwich City Council and the Tyndall Centre for Climate Change Research at the University of East Anglia.

NORWICH City Council
Tyndall°Centre for Climate Change Research
UEA University of East Anglia

Review of Norwich and Norfolk Climate Projections and potential adaptations to these impacts.

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Summary:

Overall, climate projections show Norwich and Norfolk are expected to warm, with summers becoming warmer and drier and winters becoming warmer and wetter by 2040[i].

Summer temperature is likely to be highest in South Norfolk[ii]. Summer precipitation shall be highest in East Norfolk[iii]. Winter air temperatures are projected to warm across Norfolk coastlines and least across inland Norfolk[iv]. Coastal areas will experience warmer temperatures than inland air temperatures, as the warmth of the sea is expected to moderate coastline air temperatures[v]. Projected winter precipitation rates show North and East Norfolk shall have highest rates of precipitation and inland Norfolk shall experience the lowest rates of precipitation[vi].

Norfolk is on low-lying land[1], with much of East England being 60 metres below sea level[2]. Norfolk wraps around the East coast of England, making it vulnerable to flooding and sea level rise [SLR][3]. Norfolk is an agricultural county, providing the UK's main supplies of cereal crops[4]. Norwich is city centre of Norfolk and had a population of 142,177 during 2050[5]. This is expected to grow to 152,337 by 2043[6]. 84.4% of Norwich residents are in employment[7]; 61% full-time and 39% part-time[8]. Norwich has a high population per square kilometre of 3,480 per square kilometre[9].

Overall conclusions show:

- Increasing global temperatures makes Norwich and Norfolk more susceptible to future heatwaves.

- Flooding mitigation, such as beach nourishment, greatly reduces the number of people affected by flooding from 986,300 to 5,600[vii]. Mitigating Broadland flooding also mitigates flooding within Norwich, given connected river paths.

- Adaptation should largely include adapting housing in flood plains, adapting health care buildings to heatwaves, creating new habitat space across Norfolk for endangered species on the Broads and planting new crops which increase in yield count as temperature increases.

This report builds upon a comprehensive literature review of sources varying broadly between academic research, Met Office and Norwich City Council documentation. OpenCLIM data, in form of maps, are analysed thematically throughout this text, in support of literature review analysis. The UK Adaptation Inventory has also been consulted, to understand adaptations previously proposed for issues discussed, which are transferrable to Norwich and Norfolk.

Impacts of projections on water storage and utilisation

- Expected decrease in available water due to changes to rainfall patterns.
- Adaptations include water transfer pipelines and relocation of water assets within the River Wensum.

Norfolk is identified as the driest region of England because of climate change, agricultural irrigation demands and population growth[viii]. Projections suggest an increased annual precipitation rate of up to 5% by 2100, compared to 1960-1990 baseline climates[ix]. Despite this increase, the amount of readily available water for storage is projected to decrease, because of shorter and heavier rain burst patterns and higher rates of evaporation from reservoirs[x]. Yusoff et al., suggest that across East England, there will be decreased periods of recharge in water basins, due to lower rates of precipitation over summer and higher rates of evapotranspiration during Autumn. West Norfolk is particularly challenged because of projected longer and drier summers compared to other regions of Norfolk[xi]. Water availability shall negatively affect the work of health services during droughts and could have moderated usage in future.

The main uncertainties surrounding water storage and utilisation when studying hydrological models are the inclusion of water quality in models and the inclusion of management in models[xii]. One current adaptation is Anglian Waters £365 million water transfer pipeline, which shall transport water from Lincolnshire to areas of East England[xiii]. Also, the relocation of assets within the River Wensum, to areas across Norwich and Broadland is underway, with the aim to improve hydro-ecological conditions in the Wensum and to address deficits in Norwich and Broadland water resources[xiv].

Impacts of projections on Norfolk Coastlines, SLR and flooding

- Norfolk is at very high risk of flooding due to its proximity to the coast and the risk of SLR.
- East Norwich housing development is being constructed on a flood plain and therefore is at high risk of flooding.
- Adaptations include flood defence walls, barriers and back-up power generators for flood events.

Norwich and Norfolk are at substantial risk of flooding due to SLR. Norfolk's coastline is one of the fastest eroding coastlines in Europe[xv] and with expected SLR of 0.54m for East England by 2100, erosion shall be of increased risk[xvi]. If there are no adaptations and continued SLR, approximately 986,300 people will experience flooding across the UK in 2080, however with adaptation measures such as flood dykes, this reduces to 5,600[xvii]. Great Yarmouth, when under most extreme UK Climate Projections 18 Outputs from the Met Office, is projected to experience SLR of between 0.2-0.4m by 2050 and 0.6-1m of SLR by 2100[xviii]. Broads Future Initiative suggest a rise of 1m by 2100 would result in 75% of Broadland being below sea level[xix]. Furthermore, Jeff Price argues an increase of 0.5m SLR would transport saline waters into Broadland's freshwater, so with projected rise being 0.98m, it is highly likely saline water will pollute freshwater supplies[xx].

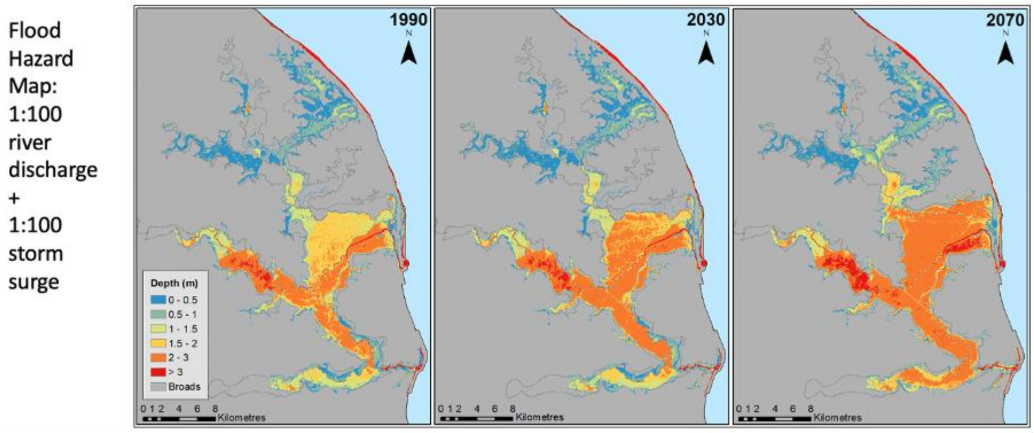


Figure 1 – projected flood risk increases in Broadland, supplied by Katie Jenkins, Tyndall Centre UEA

Figure 1 shows flood risk increases per year, with highest risk areas being within West Broadland and low risk areas being within North Broadland. In West Broadland, depth ranges 2 to <3m. The size of land in West Broadland becoming <3m in depth increases between 1990-2070. North Broadland has the lowest depth overall, ranging 0 to 1m depth increase.

Figure 2 – proposed sites for East Norwich housing development, Allies and Morrison, 2021:7

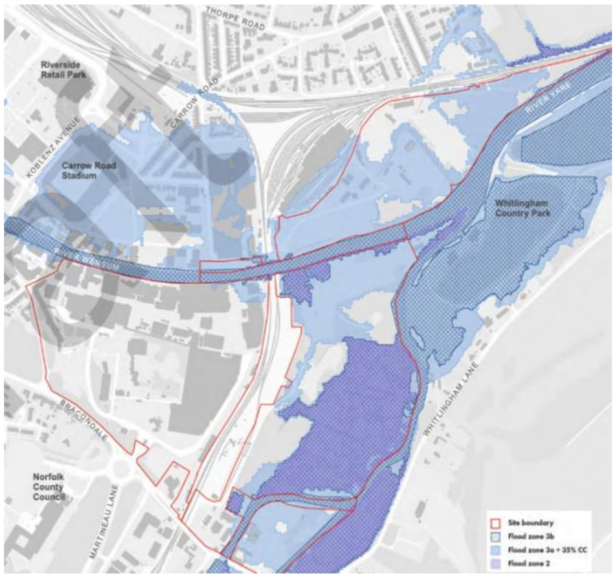


Figure 3 – flood zones within the East Norwich Development, Allies and Morrison, 2021:28

Figures 2 and 3 shows the location of East Norwich housing development on high-risk flood plains. Developments 2, 3 and 4 fall within identified flood plains, meanwhile Carrow Works [Site 1] remains outside the flood plain. Projected SLR and increasing precipitation rate across winter seasons will increase this flood risk.

A main uncertainty associated with SLR and flooding is the unknown frequency of future floods. The frequency of flood is affected by unknown future mitigations which could reduce SLR and flood frequency. Adaptation actions for Norwich and Norfolk which should be prioritised include investment in flood defence walls, barriers, and back-up generators[xxi]. In South-East England, Affinity Water calculated areas groundwater flood trigger levels and gain advanced warning of a flood, ultimately giving more time to prepare the area[xxii]. This adaptation measure could be implemented in the East Norwich site.

Existing adaptations to flooding in the UK Adaptation Inventory consider a range of facilities and infrastructures which could be affected in future and there is understanding amongst regional companies and infrastructures of the necessity to adapt and prepare high-risk areas. TechUK propose uninterrupted power supplies, from batteries, flywheels and generators, to give continuous power supply to data centres during a flood[xxiii]. This could be used across Norwich and Norfolk to provide power for residents, emergency services and local infrastructure and could be of benefit to East Norwich homeowners.
South-East water suggests upgrading pump duty and pump types at boreholes, to ensure sufficient range across the region are well supplied[xxiv]. This could be useful for ensuring water demands across Norfolk are met in future, given reliance on Norfolk Chalk Aquifers by Anglian Water[xxv].

SP energy network completed tree clearing in areas of high-risk, to prevent trees falling on power lines during a flood event[xxvi]. Upstream tree planting can be used to slow flooding expansion, so by clearing trees, it is likely to reduce risk of power failure. This could further support Norwich and Norfolk's high-risk areas during a flood event, given Norfolk's overall rural environment.

Glasgow airport improved its runway surface drainage system in grassed areas of the airfield by removing thatch build-up, which reduced localised ponding[xxvii]. Norwich Airport could therefore remove its own grassed areas on its airfield.

Impact of projections on Norfolk agriculture

- Temperature increase causes some crops, such as Wheat, to increase in yields, due to more suitable temperature conditions.
- Uncertainty in frequency of future extreme weather events and potential pests.
- Adaptations include harvesting drought resistant and less water intensive crops

Norfolk's produce includes a third of England's potato crop, sugar beet, cereal crops [including wheat and barley] and pig farming[xxviii]. Some projections show some crops increase in yields, making agricultural work more productive. However, rising temperatures and declining precipitation patterns require further irrigation which places further stress on water availability. There is a total of 1.4 million hectares in East Anglia and one third of this is used for farming Wheat[xxix]. Wheat's yield change under HadCM3 GCM projections for 7 SRES emissions, showed even at A1F1, the greatest warming scenario, although yields decreased between 2050-2080, total yield was above baseline levels of 1972-2000[xxx]. This wheat product was irrigated and rain-fed. Further studies show crops such as spring wheat, soybeans and sunflowers all experience increasing yields under global warming of 2°C during 2030-2060 and no adaptation[xxxi].

Variable	Emissions Scenario	5th percentile change	10th percentile change	50th percentile change	90th percentile change	95th percentile change
mean summer temperature (°C) 2030-2049	RCP2.6	0.3	0.5	1.6	2.6	2.9
	RCP4.5	0	0.3	1.3	2.3	2.6
	RCP6.0	0	0.2	1.2	2.3	2.6
	RCP8.5	0.2	0.6	1.6	2.8	3.1
mean winter temperature (°C) 2030-2049	RCP2.6	-0.2	0.1	1	2	2.3
	RCP4.5	-0.1	0.2	1.1	1.9	2.2
	RCP6.0	-0.1	0.2	1	1.9	2.1
	RCP8.5	0.1	0.3	1.3	2.3	2.6
mean summer precipitation (%) 2030-2049	RCP2.6	-37	-31	-11	10	16
	RCP4.5	-38	-32	-10	12	19
	RCP6.0	-37	-31	-10	13	20
	RCP8.5	-43	-36	-13	12	19
mean winter precipitation (%) 2030-2049	RCP2.6	-8	-5	6	18	22
	RCP4.5	-8	-5	6	17	21
	RCP6.0	-8	-5	5	17	20
	RCP8.5	-7	-4	8	21	25

Figure 4 – temperature and precipitation change relating to RCP projections for East England, Lovett et al., 2019:15

RCP8.5 projections show summer precipitation is likely to decrease, summer temperatures are likely to increase, winter precipitation is likely to increase and winter temperatures are likely to increase. In relation to Norfolk's agriculture, a warming climate supports yield increase in some crops. However, less precipitation in summer may result in some crop yields decreasing or ultimately not surviving drought conditions.

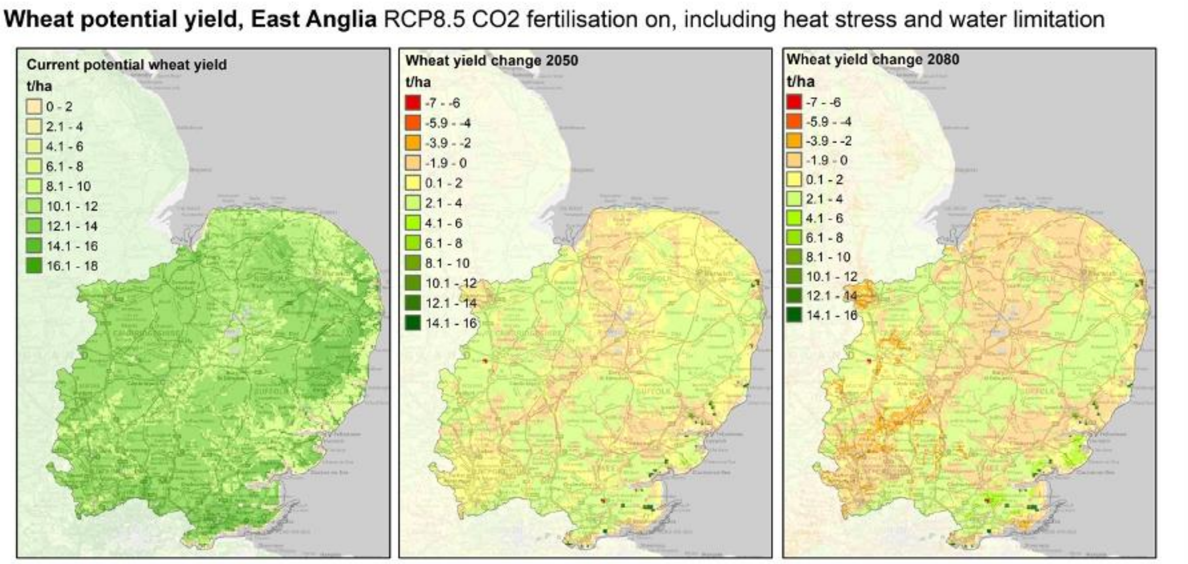


Figure 5 – change in future wheat yield, supplied by Jeff Price, Tyndall Centre UEA

Wheats yield potential is currently highest in East and South regions of East Anglia and lowest in central East Anglia and along the coastline.

In 2050, wheat productivity yield decreases and is highest across East, South, and West regions of East Anglia, largely by 2.1- 4t/ ha. North of East Anglia, yield productivity decreases between 0.1 to -3.9/ha. Small eastern areas have very high wheat yield productivity of 8.1 – 16t/ha.

In 2080, wheat yield productivity decreases overall but is highest in the South-East, South and North-West of East Anglia. North regions of East Anglia have yield productivity of -1.9 – 2t/ ha. West of East Anglia, yield productivity ranges between -3.9 – 4.

Overall, there is improved suitability for the cultivation of 90-95% of current UK cropland during 2030, under A1B mitigation scenarios and model projections[xxxii]. There is uncertainty surrounding how future extreme weather events and changes to pests and diseases will affect crop production[xxxiii], placing 50,000 agricultural jobs at risk[xxxiv]. There is further uncertainty in understanding how increases in Carbon Dioxide [CO2] could affect plants physiology and how this could alter its productivity[xxxv]. 18% of East Anglian farmers have already begun adapting to long-term climate, by harvesting drought resistant or less water intensive crops enhance survival rate and lower reliance on irrigation[xxxvi]. With precipitation rates decreasing across summer but increasing during winter, this could be an important consideration for more East Anglian farmers. Community outreach teams could work alongside farmers to advise on drought resistant crops and yield increasing crops under new climates.

Impact of projections on Broadland Biodiversity

- 60% of Broadland species rely on freshwater supply, if Broadland were to flood, this could put these species at risk of extinction.
- Adaptations include monitoring salinity levels in boreholes to determine saline water intrusion in freshwater areas. Providing new habitat space is also important.

Norfolk Broadland is highly vulnerable to climate change impacts, as SLR, flooding and rising temperatures causes unsuitability for many species. Furthermore, the number of jobs catering to Norfolk's tourism industry equate to 18.4% of Norfolk's overall employment[xxxvii]. Without Broadland tourism, due to ecological disturbance, this could impact local economies.

Norfolk Broadland is located on low-lying land, which makes it vulnerable to flooding[xxxviii]. SLR has potential to damage crops, reduce soil yields and alter the habitat and vegetation available to species[xxxix]. Because of changes to available habitats and vegetation, new species would establish themselves in Broadland, while others may migrate, or risk extinction.

In particular, the Swallowtail butterfly relies on the Broad's freshwater supply and milk parsley presence. However, with freshwater supplies likely to be polluted with saline waters and a lack of mobility due to milk parsley's non-existence 30 miles from the Broadland, Swallowtail butterflies are at risk of extinction[xl].
An uncertainty surrounding SLR in the Broadland is how groundwater levels and salinity across Broadland could change because of climate change, with particular implications on land drainage unknown[xli]. Affinity water have previously drilled boreholes between the coast and a pumping site, to monitor salinity levels within samples overtime. The presence of saline water in the samples taken are tested to calculate whether saline intrusion has occurred. This method could be used to monitor salinity levels between Broadland and the coast[xlii].

Projected temperature rise is shown to impact Broadland positively and negatively. RCP8.5 climate projections suggest by 2080, winter, spring and summer temperatures shall become 3 months early [xliii], for example, May/ June temperatures shall be similar to temperatures currently experienced in August. The risks associated with this temperature increase include the production of algae blooms and growth of surface vegetation and changes to species distribution [with warm temperature areas suiting warm-water species]. There is also risks of drier soils and drought risk, which both affect land use choices[xliv]. Altering choice of plant species could affect Broadland water quality, due to runoff from planted areas into river systems.

Temperature increase create unsuitable conditions for many mammals, reptiles and plants that currently inhabit the area, including water voles, great crested newts and common ash trees[xlv]. However, some temperature increase improves suitability for some species of bird including black-crowned night heron, cattle egret and little bittern[xlvi]. Temperature projections are unable to accurately predict future temperature change due to unknown events and mitigation measures.

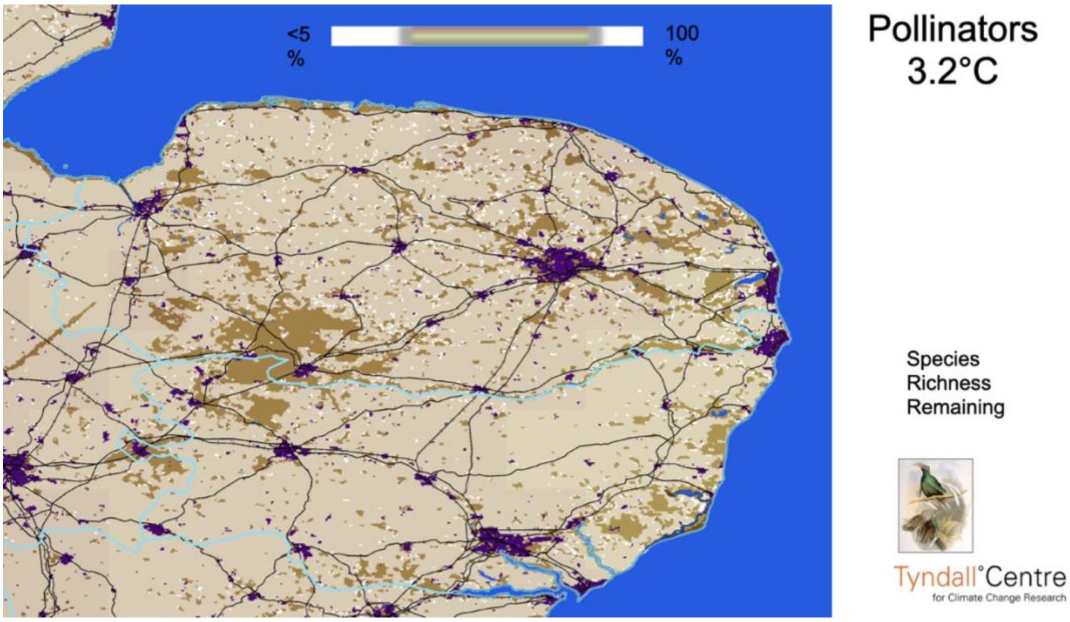


Figure 6 – pollinator species richness across East Anglia, supplied by Jeff Price, Tyndall Centre UEA

At 3.2°C warming, pollinator biodiversity has decreased across Norfolk but remains highest on the south-east Norfolk coastline with a pollinator biodiversity range of 40-45%. Remaining pollinator biodiversity richness remains 35% across North and West Norfolk and suburbs surrounding Norwich.

An adaptation action of priority should be to work with East Anglian farmers to provide new habitat space for at risk species, as has been performed by Natural England, who worked with farmers in Essex to produce new suitable habitat space for Fishers Marine Moth[xlvii].

Impacts of projected extreme weather

- Air temperature is projected to increase to ~14 degrees C in Norwich by 2080.
- Heat related deaths increase as temperature increases, with up to 20 deaths per year across Norwich, at 3°C warming.
- Adaptations include retrofitting buildings and adapting behaviours during heatwaves, e.g., closing windows and blinds which receive afternoon sunlight.

Extreme weather events such as flooding, heatwaves and drought are due to increase in future. Annual precipitation is projected to increase up to 5% by 2100, compared to 1960-1990 baseline levels[xlviii]. Despite this, flood peaks are projected to decrease in East England, due to high soil moisture during summer and autumn, ultimately causing a decrease in peak flood flow[xlix]. However, this result is uncertain since the study used one climate model and scenario, without considering different scenarios. Similar findings are recorded by the Met Office, suggesting there is no evidence for significant changes to the amount of future storm surges[l]. Uncertainties surrounding annual precipitation increase include different projections and scenarios producing different results, ultimately meaning no definitive range of precipitation. Adaptation methods which tackle flooding as a product of increased precipitation include enhancing spillways, as seen by United Utilities Water, to adapt built landscapes to increasing flood risk[li].

Annual temperatures are expected to increase by 2.5-3% by 2100 when compared to the 1960-1990 baseline[lii, liii], however droughts are projected to increase in frequency, due to increasing heatwaves and temperatures. Adaptation measures which should be considered for Norwich and Norfolk include Peatland restoration, as seen by Lake District Peat Restoration. Outcomes of this restoration were peatland resilience to heatwaves, allowing for natural carbon sequestration and flood alleviation fulfilment[liv].

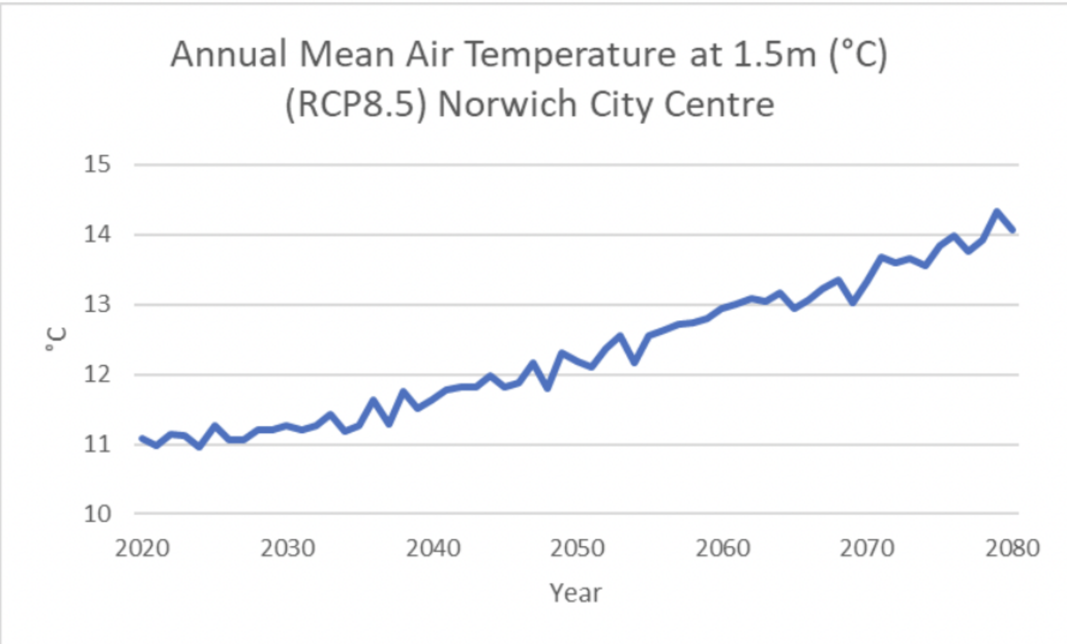


Figure 7 – projected warming in Norwich, supplied by Katie Jenkins, Tyndall Research Centre UEA

Temperature in Norwich overall increases per year. In 2020, temperature begins at 11.1°C and by 2080 temperature becomes 14°C. Temperature increases sharply after 2049, rising from 11.9°C in 2049 to 12.6°C in 2053. Temperature increases between 2054-2062 by +0.8°C. Temperature continues increasing, reaching 13.8°C by 2070 and 14°C by 2080.

Seasonal temperature increases, while seasonal precipitation decreases as RCP scenario and percentile change both increase. This suggests summer temperatures will become warmer, winter temperatures will become warmer, summer precipitation will decrease, and winter precipitation will increase.

Public health services with no building or equipment adaptations are highly vulnerable. Heatwaves may affect hospital equipment, cold storage medication units and air conditioning, for staff and patients[lv]. An adaptation measure to urgently implement is building retrofitting to ensure durability during heat waves. Also, Cold waves, such as 2017s beast from the East, could increase travel times and access to hospitals, slow ambulance response timings and increase healthcare demands[lvi]. An adaptation measure which would help overcome many of cold wave issues is fitting ambulances with modified winter wheels, which have better grip during periods of snow and ice[lvii].

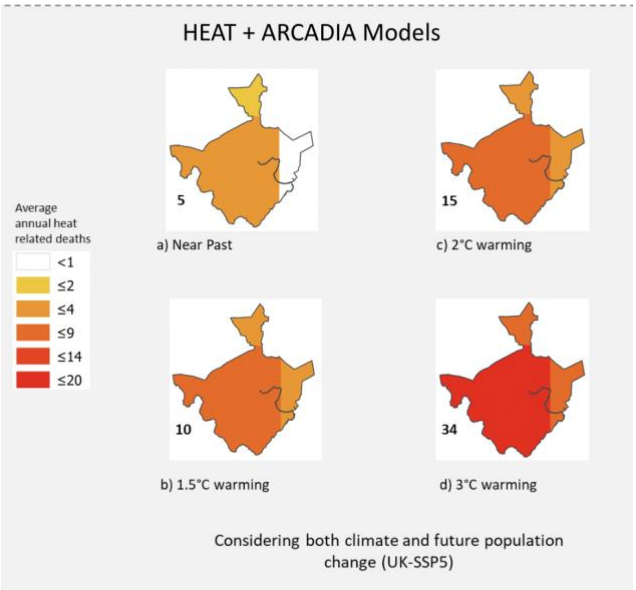


Figure 8 – heat mortality increases as temperature increases, supplied by Katie Jenkins, Tyndall Centre UEA

Average annual heat related deaths [AAHRD] increase by amount, as average air temperatures increase.

Map A shows east Norwich is least affected by heatwaves and therefore AAHRD with a score of <1. North Norwich is moderately affected with <2 AAHRD. Central, South and West Norwich are most affected with <4 AAHRD.

Map B shows with 1.5°C of warming, North and East Norwich's AAHRD increases to the same rate of <4. Central, South and West Norwich continue to be most affected with <9 deaths.

Map C shows no difference in AAHRD in relation to map B.

Map D shows with 3°C warming, North and East Norwich AAHRD increases to <9. Central, South and West Norwich has the highest AAHRD rate of <20.

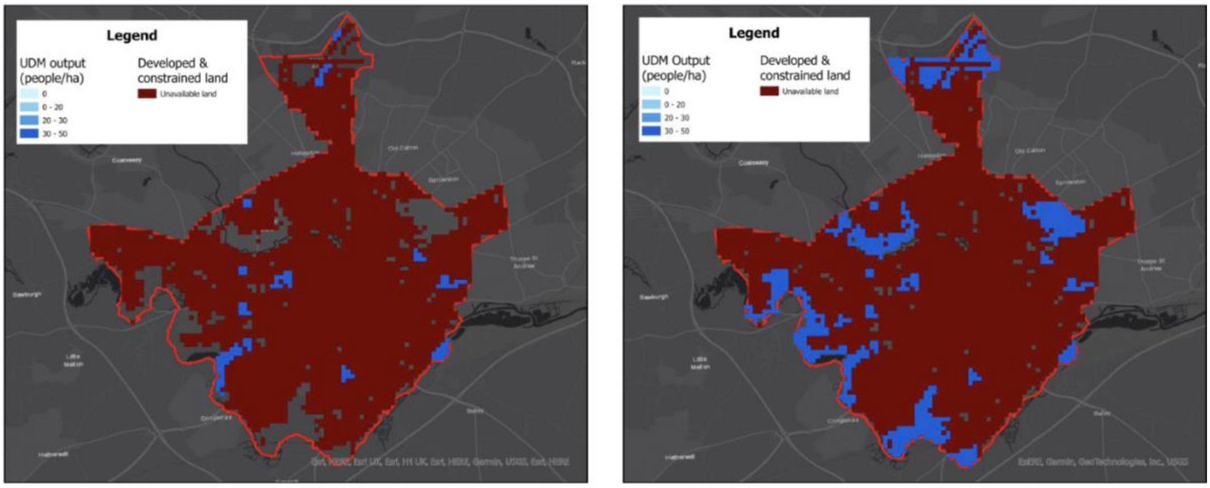
Norwich and Norfolk Hospital [N&N] is arguably at high risk of experiencing increasing heat related deaths, due to its proximity to West Norwich. However, this is uncertain due to N&N not being within Figure 4 boundaries. N&N can adapt facilities for patients during heatwaves by keeping windows which receive sun during the afternoon closed, shutting curtains to these windows during afternoons and opening windows at night[lviii].

Current heatwave adaptations listed in the UK adaptation inventory match up against anticipated climate change risks, due to a large focus on retrofit and adapting buildings and transport infrastructure. Risks outlined above show heatwaves impact peoples physical wellbeing, health care buildings adaptiveness and potentially limit transportation links. Khare et al., 2015 suggest opening windows at night, closing windows and curtains which receive afternoon sun and using electric fans[lix]. Similarly, Barborska-Narozny et al., suggest use of black-out blinds and mechanical extraction fan ventilation[lx]. Both Khare et al., and Barborska-Narozny et al., findings support retrofitting N&N hospital, in addition to other Norwich local infrastructure and domestic housing. The US Environmental Protection Agency propose tree planting to adapt to climate change, due to trees lowering surface and air temperature, due to the provision of shade and evapotranspiration[lxi]. TfL propose heatwave adaptation by enforcing speed restrictions to prevent trainlines buckling[lxii]. This could be implemented by East Anglian rail and Norwich train station could become responsible for observing track conditions. Port of Felixstowe have adapted tarmac road surfaces by replacing tarmac with heat resilient surfaces[lxiii]. This is to prevent operation disruption but could be considered for Norwich's city centre roads particularly. Barriers to this adaptation include unknown heat resilient alternatives to Tarmac, used by Port of Felixstowe, as this was not elaborated upon. There is also little consideration for the focus on warming buildings during winter and the consequences this shall have for heatwave periods.

Impact of projections on building and infrastructure quality

- Population per square kilometre is projected to increase.
- Suitable land for development is located near Norwich's boundaries, constrained land which cannot be developed is within Central Norwich.
- Adaptations include a retrofitting workforce, to ensure continuity across building refurbishments.

70% of East England's existing buildings will be used in 2050[lxiv]. It is important that existing buildings, constructed with consideration of past climates and weather conditions, adapt to projected future changes. This makes infrastructure suitable for the future and more likely to withstand extreme events. An example of adaptation is Goldsmith Street in Norwich. Despite being a newly constructed housing area, planning considerations such as rooftop angles ensuring each terrace doesn't block sunlight reaching other houses [lxv], maximises heat and light from available daylight, showing efforts to decarbonise and adapt to warming. These planning considerations also have potential to reduce the long-term demand for heating in buildings.



UKSSP4 2050 UKSSP5 2050

Figure 9 – population increase between SSP4 and SSP5 across Norwich, supplied by Katie Jenkins, Tyndall Centre UEA

UK SSP4 2050 shows population increase largely across West and South-West Norwich. Projected population per hectare in this area is between 30-50people/ ha. UKSSP5 2050 shows increased population per hectare. West Norwich remains the area with highest population per hectare of 30-50 people/ ha, with a larger data area compared to UKSSP4 2050. Areas of population per hectare have increased across North and East Norwich, to 30-50 people/ ha. Areas along the South Norwich boundary line and areas towards central south Norwich, measure 30-50 people/ ha.

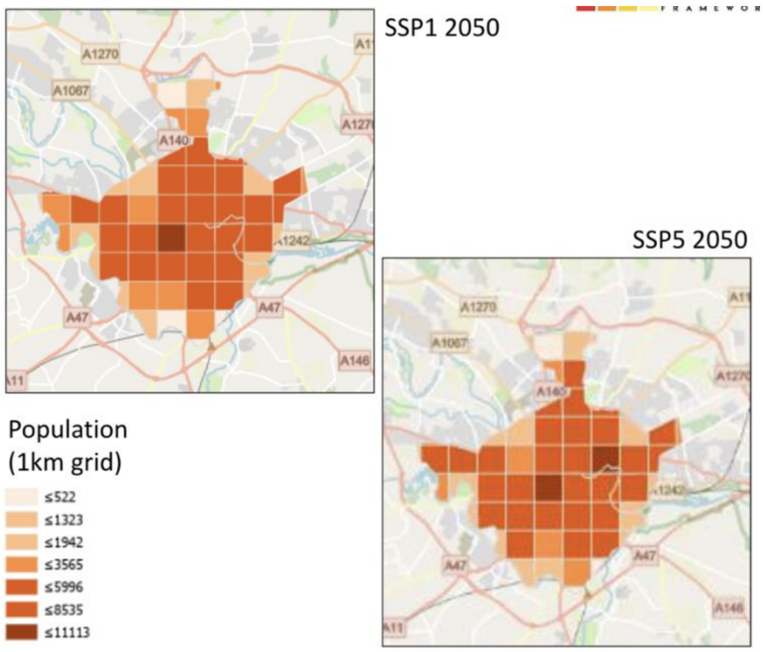


Figure 10 - population increase across Norwich from SSP1 in 2050 to SSP5 in 2050, supplied by Katie Jenkins, Tyndall Centre UEA

SSP1 2050 shows population is highest in central South-West Norwich at <11113 and population is lowest on the outskirts of Norwich with some areas scoring <522. North Norwich has between <522 to <1323 and South Norwich has between <522 and <3565 people per 1km, showing decreasing population along the boundary line.

SSP5 2050 shows increased population per 1km. Central North-East Norwich becomes an area with highest population per 1km of <11113, in addition to Central Southwest Norwich. Population increases in South Norwich's outskirts, compared to SSP1 2050, ranging <1323 to <3565.

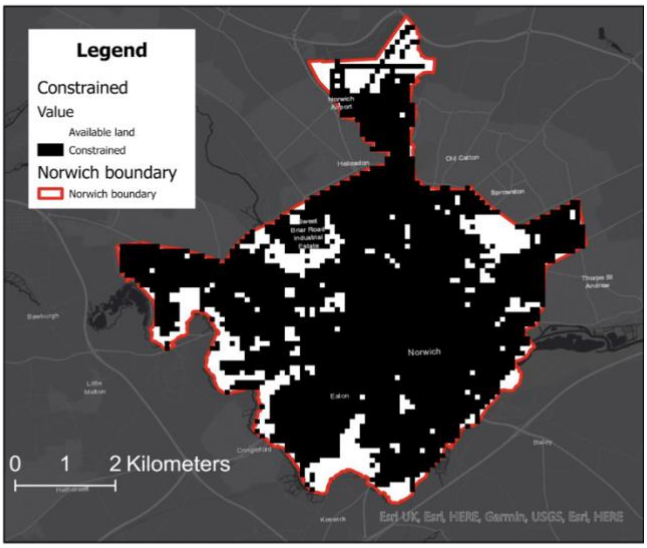


Figure 11 – constrained land in Norwich, supplied by Katie Jenkins, Tyndall Centre UEA

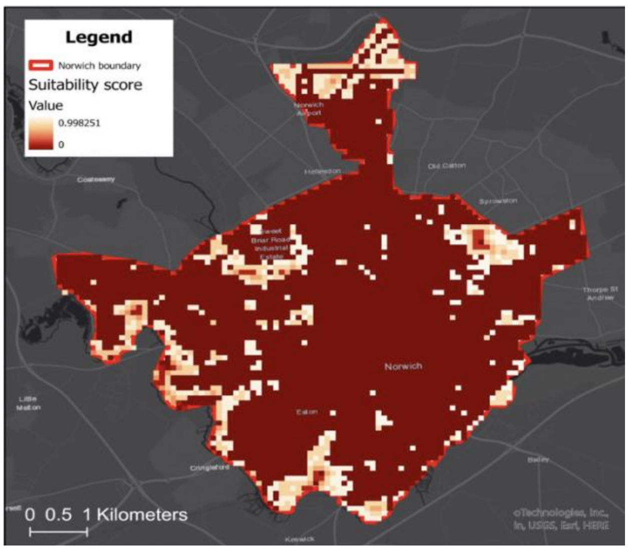


Figure 12 – suitable land in Norwich, supplied by Katie Jenkins, Tyndall Centre UEA.

Figure 12 shows Norwich's outskirts has available land for development and Central Norwich is constrained land which cannot undergo development. North Norwich outskirts mainly consist of available land, however not all of this is available. North-East Norwich has an area of available land, South of Sprowston. East Norwich is largely constrained land. South-East Norwich has available land along the Norwich boundary line. West Norwich has the largest amount of available land, following the South-West Norwich boundary line, across Briar Road Industrial Estate and North of Eaton.

Figure 13 shows highest urbanisation suitability is along Norwich's boundary line. East Norwich has a large area of suitable land with a score of ~0.99 to 0.2. South Norwich has suitable land adjoined to the boundary line, which ranges between ~0.1 and ~0.99. There is suitable land in North-West Norwich surrounding Briar Road Industrial Estate.

Uncertainties surrounding the impact of projections on building infrastructure include uncertain levels of SLR and temperature rise, with flood risk increasing in future for some areas across Norwich. Osbourn argues for a workforce which retrofits houses to meet future adaptations to council's planning policies. The team would work with local businesses and educational institutions[lxvi] standards.

Figures:

1. Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA
2. Allies and Morrison, 2021. Draft East Norwich Masterplan Stage 1 Part 1. [Online]. Available at: https://www.gnlp.org.uk/sites/gnlp/files/2021-11/D1.4N%20ENMPart1.pdf . Accessed 30th June 2022. Pg. 7.
3. Allies and Morrison, 2021. Draft East Norwich Masterplan Stage 1 Part 1. [Online]. Available at: https://www.gnlp.org.uk/sites/gnlp/files/2021-11/D1.4N%20ENMPart1.pdf . Accessed 30th June 2022. Pg. 28.
4. Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 15.
5. Currently unpublished, kindly supplied by Jeff Price, Tyndall Centre UEA
6. Currently unpublished, kindly supplied by Jeff Price, Tyndall Centre UEA
7. Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA
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9. Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA
10. Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA
11. Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA

    Currently unpublished, kindly supplied by Katie Jenkins, Tyndall Centre UEA

Summary box:

[1] Britannica, undated. Norfolk. [Online]. Available at: https://www.britannica.com/place/Norfolk-county-England . Accessed on 1st July 2022. Pg. 1.

[2]Met Office, 2016. Eastern England: Climate. [Online]. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/regional-climates/eastern-england_-climate---met-office.pdf . Accessed 1st July 2022. Pg. 1.

[3]Britannica, undated. Norfolk. [Online]. Available at: https://www.britannica.com/place/Norfolk-county-England . Accessed on 1st July 2022. Pg. 1.

[4]Met Office, 2016. Eastern England: Climate. [Online]. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/weather/learn-about/uk-past-events/regional-climates/eastern-england_-climate---met-office.pdf . Accessed 1st July 2022. Pg. 1.

[5]Norfolk Insight, undated. Population Norwich. [Online]. Available at: https://www.norfolkinsight.org.uk/population/reports/#/view-report/1d8c05aa974845358d3e326c6f11a11f/E07000148 . Accessed on 1st July 2022. Pg. 1.

[6]Norfolk Insight, undated. Population Norwich. [Online]. Available at: https://www.norfolkinsight.org.uk/population/reports/#/view-report/1d8c05aa974845358d3e326c6f11a11f/E07000148 . Accessed on 1st July 2022. Pg. 1.

[7] NOMIS, undated. Official labour market statistics. [Online]. Available at: https://www.nomisweb.co.uk/reports/lmp/la/1946157237/printable.aspx . Accessed on 1st July 2022. Pg. 1.

[8] Norwich Business Improvement District, 2019. Final state of the city business prospectus 2019. [Online]. Available at: https://norwichbid.co.uk/assets/downloads/Norwich-Data-State-of-the-City/Final-State-of-the-City_Business-Prospectus-2019.pdf . Accessed 1st July 2022. Pg. 3.

[9] Varbes, undated. Demographics of Norwich. [Online]. Available at: https://www.varbes.com/demographics/norwich-demographics . Accessed on 1st July 2022. Pg. 1.

[i] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 4.

[ii] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 8.

[iii] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 8.

[iv] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 8.

[v] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 12.

[vi] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 8.

[vii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 3.

[viii] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 4.

[ix] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 67.

[x] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 14.

[xi] Yusoff, I., Hiscock, K., Conway, D., 2002. Simulation of the impacts of climate change on groundwater resources in eastern England. *Sustainable Groundwater Development*, 193. Pg. 325.

[xii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 100.

[xiii] Jenkins, K., Ford, A., Robson, C., Nicholls R.J., 2022. Identifying adaptation 'on the ground': Development of a UK adaptation inventory [Version 1]. [Online]. Available at: https://www.nismod.ac.uk/openclim/adaptation_inventory . Accessed on 29th June 2022.

[xiv] Anglian Water, 2020. Anglian Water's Climate Change Adaptation Report 2020. [Online]. Available at: https://www.anglianwater.co.uk/siteassets/household/in-the-community/climate-change-adaptation-report-2020.pdf . Accessed on 30th June 2022. Pg. 18.

[xv] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 15.

[xvi] ClimateUK, 2012. *A summary of climate change risks for the east of England to coincide with the publication of the UK climate change risk assessment [CCRA]*, Online: ClimateUK. Pg. 3.

[xvii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 3.

[xviii] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 4.

[xix] Broadland Futures Initiative, undated. The future impacts of Climate Change. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/374344/The-Future-Impacts-Of-Climate-Change-Web-based-Version.pdf . Accessed on 22nd June 2022. Pg. 10.

[xx] Price, J., 2013. The potential impacts of climate change on the Norfolk Broads. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0030/187815/Jeff-Price-report.pdf . Accessed on 24th June 2022. Pg. 7.

[xxi] Jenkins, K., Ford, A., Robson, C., Nicholls R.J., 2022. Identifying adaptation 'on the ground': Development of a UK adaptation inventory [Version 1]. [Online]. Available at: https://www.nismod.ac.uk/openclim/adaptation_inventory . Accessed on 29th June 2022.

[xxii] Affinity Water, 2015. Adapting to Climate Change. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/477213/climate-adrep-affinity-water.pdf . Accessed on 29th June 2022. Pg. 26.

[xxiii] TechUK, 2017. techUK Data Centres Technical Committee briefing note: emergency generation. [Online]. Available at: https://www.techuk.org/asset/DFCB2EC1-26F1-41BA-962C40579DF79597/ . Accessed on 13th July 2022. Pg. 1-2.

[xxiv] Southeast Water, 2015. Climate change Adaptation Report. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/462907/climate-adrep-southeast-water.pdf . Accessed on 13th July 2022. Pg. 34.

[xxv] Anglian Water, 2019. Appendix 1: Water resource zone characteristics. [Online]. Available at: https://www.anglianwater.co.uk/siteassets/household/about-us/aws-final-drought-plan-2019---appendix-1.pdf . Accessed 13th July 2022. Pg. 25.

[xxvi] SP Energy Networks, 2015. Climate Change Adaptation Report Round 2 Update. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/479266/clim-adrep-sp-energy-networks-2015.pdf . Accessed on 13th July 2022. Pg. 20-21.

[xxvii] Glasgow Airport, undated. Climate Change Adaptation Progress Report for Glasgow Airport. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/544716/climate-adrep-glasgow-airport.pdf . Accessed on 13th July 2022. Pg. 8.

[xxviii] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 15.

[xxix] ClimateUK, 2012. *A summary of climate change risks for the east of England to coincide with the publication of the UK climate change risk assessment [CCRA],* Online: ClimateUK. Pg. 14.

[xxx] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 84.

[xxxi] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 85-86.

[xxxii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 91.

[xxxiii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 81.

[xxxiv] ClimateUK, 2012. *A summary of climate change risks for the east of England to coincide with the publication of the UK climate change risk assessment [CCRA],* Online: ClimateUK. Pg. 15.

[xxxv] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 82.

[xxxvi] Rey, D., Holman, I., Knox, J., 2017. Developing drought resilience in irrigated agriculture in the face of increasing water scarcity. *Regional Environmental Change*, 17. Pg. 1534.

[xxxvii] Whymark, B., 2018. Norfolk tourism industry breaks records in 2017 for visitor numbers and economic value. *EDP*, 18 September.

[xxxviii] Broadland Futures Initiative, undated. The future impacts of Climate Change. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/374344/The-Future-Impacts-Of-Climate-Change-Web-based-Version.pdf . Accessed on 22nd June 2022. Pg. 7.

[xxxix] Broadland Futures Initiative, undated. The future impacts of Climate Change. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/374344/The-Future-Impacts-Of-Climate-Change-Web-based-Version.pdf . Accessed on 22nd June 2022. Pg. 16-17.

[xl] Broadland Futures Initiative, undated. The future impacts of Climate Change. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/374344/The-Future-Impacts-Of-Climate-Change-Web-based-Version.pdf . Accessed on 22nd June 2022. Pg. 17.

[xli] Broadland Futures Initiative, undated. The future impacts of Climate Change. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0025/374344/The-Future-Impacts-Of-Climate-Change-Web-based-Version.pdf . Accessed on 22nd June 2022. Pg. 15.

[xlii] Affinity Water, 2015. Adapting to Climate Change. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/477213/climate-adrep-affinity-water.pdf . Accessed on 29th June 2022. Pg. 23.

[xliii] Price, J., 2013. The potential impacts of climate change on the Norfolk Broads. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0030/187815/Jeff-Price-report.pdf . Accessed on 24th June 2022. Pg. 6.

[xliv] Price, J., 2013. The potential impacts of climate change on the Norfolk Broads. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0030/187815/Jeff-Price-report.pdf . Accessed on 24th June 2022. Pg. 7.

[xlv] Price, J., 2013. The potential impacts of climate change on the Norfolk Broads. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0030/187815/Jeff-Price-report.pdf . Accessed on 24th June 2022. Pg. 54-55.

[xlvi] Price, J., 2013. The potential impacts of climate change on the Norfolk Broads. [Online]. Available at: https://www.broads-authority.gov.uk/__data/assets/pdf_file/0030/187815/Jeff-Price-report.pdf . Accessed on 24th June 2022. Pg. 52.

[xlvii] Natural England, 2012. Natural England's climate change risk assessment and adaptation plan. [Online]. Available at: http://publications.naturalengland.org.uk/publication/216300 . Accessed on 28th June 2022. Pg. 6.

[xlviii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 67.

[xlix] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 117.

[l] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 117.

[li] Lovett, A., Dockerty, T., Sunnenburg, G., Goodess, C., Quere, C.L., 2019. *Scoping report for the New Anglia LEP: Climate Change Adaptation and Carbon Reduction Action Plan.* Norwich: University of East Anglia Consulting. Pg. 18.

[lii] UK Met Office, 2011. Climate: observations, projections and impacts. [Online]. Available at: https://nottingham-repository.worktribe.com/index.php/output/1010959/climate-observations-projections-and-impacts . Accessed on 20th June 2022. Pg. 67.

[liii] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 4.

[liv] Lake District National Park, 2015. Lake District National Park Climate Change Adaptation Report- 2nd Update. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/503255/climate-adrep-lake-district-national-park-update.pdf . Accessed on 29th June 2022. Pg. 5.

[lv] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-

and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 14.

[lvi] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 14.

[lvii] Gentry, S., 2018. Strategies for embedding planning for extreme weather events associated with climate change in Norfolk. [Online]. Available at: https://www.norfolk.gov.uk/-/media/norfolk/downloads/what-we-do-and-how-we-work/policy-performance-and-partnerships/policies-and-strategies/environment/norfolk-county-council-extreme-weather-report.pdf . Accessed on 22nd June 2022. Pg. 5.

[lviii] Khare et al., 2015. Heat protection behaviour in the UK: results of an online survey after the 2013 heatwave. *BMC Public Health*, 15. Pg. 7.

[lix] Khare, S., Hajat, S., Kovats, S., Lefevre, C., Bruine de Bruin, W., Dessai, S., Bone, A., 2015. Heat protection behaviour in the UK: results of an online survey after the 2013 heatwave. *BMC Public* Health, 15. Pg. 7.

[lx] Bborska-Narozny, M., Stevenson, F., Grudzinska, M., 2016. Overheating in retrofitted flats: occupant practices, learning and interventions. *Building research and information,* 45 [1-2]. Pg. 52-54.

[lxi] United States Environmental Protection Agency, undated. Using trees and vegetation to reduce heat islands. [Online]. Available at: https://www.epa.gov/heatislands/using-trees-and-vegetation-reduce-heat-islands#:~:text=Trees%20and%20other%20plants%20help,to%20reduce%20urban%20heat%20islands.&text=Trees%20and%20vegetation%20lower%20surface,providing%20shade%20and%20through%20evapotranspiration. Accessed on 23rd July 2022. Pg. 1.

[lxii] TfL, 2015. Providing transport services resilient to extreme weather and climate change: 2015 update report following last report to Government in 2011. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/466602/climate-adrep-tfl.pdf . Accessed on 13th July 2022. Pg. 28.

[lxiii] Port of Felixstowe, 2015. Climate change adaptation report. [Online]. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530910/climate-adrep-port-felixstowe.pdf . Accessed on 13th July 2022. Pg. 30.

[lxiv] ClimateUK, 2012. *A summary of climate change risks for the east of England to coincide with the publication of the UK climate change risk assessment [CCRA],* Online: ClimateUK. Pg. 12.

[lxv] Wainright, O., 2019. I've seen the future and it's Norwich: the energy-saving, social housing revolution. *The Guardian,* 16 July.

[lxvi] Osborn, J., 2021. OPINION: Norwich must prepare for the effects of climate change now. *EDP*, 29 September.